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Validation of a Mountain Pine Beetle Outbreak Model for Lodgepole Pine in Central Oregon

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ABSTRACT

A predictive model of mountain pine beetle infestation developed for lodgepole pine in the intermountain region was tested for validation in the Deschutes National Forest of central Oregon. We estimated live basal area (ft^2/acre), numbers of trees, and volume (ft^3) for 16 forest strata currently in approximately the fifth year of a beetle epidemic. Using the same data, we recoded recently killed lodgepole pine trees into living trees and ran the recoded population for 5 years under the beetle model to obtain model estimates of numbers of trees, basal area, and volume. We then compared model estimates to observed estimates. The estimated correlation was 1.0, 0.90, 0.85, 0.84, and 0.84 for numbers of trees, basal area, and total, merchantable cubic foot, and board foot volumes, respectively. The model tended to underestimate survival in the largest diameter classes and overestimate survival in the smallest, but the results of this test indicate that the model performs reasonably well on average in the Deschutes National Forest.

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Introduction

The mountain pine beetle (Dendroctonus ponderosae Hopk.) is a major pest in lodgepole pine (Pinus contorta Dougl.) stands of western North America (Roe and Amman 1970). Forest managers are interested in evaluating future mountain pine beetle impacts to increase the accuracy of growth and yield predictions, and to identify problem areas where treatments against mountain pine beetle might have the highest rate of return. Cole and McGregor (1983) described a predictive deterministic computer model that estimates annual tree and volume losses and longevity of infestation based on existing stand conditions. This model has been linked to Prognosis, the major USDA Forest Service western growth and yield model, allowing forest managers to address potential impacts of the mountain pine beetle during the planning process.

The Deschutes National Forest in central Oregon recently used Prognosis with the Cole and McGregor Mountain Pine Beetle Model to develop empirical yield tables for completing its forest plans. The Mountain Pine Beetle Model was originally calibrated with data from the intermountain region of the United States. It was necessary to check the calibration and validation of the model when applied to central Oregon. The purpose of this paper is to describe the methods and results of that validation process. For our purposes, validation is defined as the process of building (or reducing) confidence in the ability of the model to approximate the behavior of beetle-induced mortality in lodgepole pine stands in the Deschutes National Forest.

The Model

Prognosis is a complex, single tree, distance independent, growth and yield simulation model used in the western United States by the USDA Forest Service (Wykoff 1984). The model predicts diameter and height increment, changes in crown sizes, and mortality for trees over a variable time period. The model periodically summarizes stand conditions in terms of stand density and yield, and is capable of simulating management activities to explore planning alternatives. Several pest models (including the Mountain Pine Beetle Model) are linked to Prognosis. These pest models modify the changes in the Prognosis-simulated population of trees to reflect the effects of a single type of pest.

The current version of the Mountain Pine Beetle Model simulates mortality of lodgepole pine by removing trees from the Prognosis list of simulated trees at the end of each year. Trees are removed based on (i) current diameter and (ii) the number of currently infested trees in that diameter class. The model removes the largest trees first, then works down through the smaller diameter trees greater than 6 inches in diameter at breast height (dbh); the model does not address trees below 6 inches dbh. Within a diameter class, the probability of an individual tree becoming infested is a function of the number of infested trees in the stand and the probability of becoming infested by a single infested tree. Given the dynamics described above, the mortality rate due to beetle infestation (in terms of basal area) generally peaks in the first few years of the outbreak. Mortality ranges from 30% to 100% of susceptible trees in a stand over a 10-year outbreak cycle, with the percentage depending on the forest habitat type of the stand (Cole and McGregor 1983).

Study Population and Data Sets

The forest under study consists of ponderosa pine (Pinus ponderosae Dougl. ex Laws), lodgepole pine, and mixed conifer forest types on the Deschutes National Forest, located in the eastern Cascades in south-central Oregon. Mountain pine beetle is a natural part of these ecosystems; there is always a certain amount of endemic infestation in the forest. Periodically the beetle goes through an epidemic cycle, with large proportions of trees in a stand attacked and killed. The available data are 1985 observations from 16 different forest strata in approximately the fifth year of a major beetle outbreak. These data come from USDA Forest Service Vegetative Resource 10-point clusters of plots, pooled into 16 strata based on similar productivity and forest type classifications (S. Beyer, pers. comm.).

Methods

The 1985 survey included all live trees as well as dead lodgepole pine identified as recently killed. We first estimated the 1985 per-acre mean and standard error of live lodgepole pine in each stratum for each of the following variables of interest: numbers of trees, basal area, total and merchantable cubic foot volume, and net board foot volume. Table 1 (page 14) lists the number of plots per stratum and the 1985 estimate of basal area based on field observations for all species and for the lodgepole pine component of each stratum.

Within the data from each stratum, we recoded all recently killed lodgepole pine trees with an unknown cause of mortality, changing them into "live" trees. Since lodgepole pine grows at a relatively slow rate (0.1 to 0.2 inches per year diameter growth), this would

approximate the stratum as it appeared in 1980, prior to the major beetle attack. We did not attempt to reduce the diameters of the sample trees to adjust for the 1980-1985 growth because a 5-year diameter increment was not thought to be significant. Growth and mortality for each 1980 stratum was then projected for 5 years under the Prognosis Model with the Mountain Pine Beetle Mortality Model. The annual diameter increment during these model runs was set close to 0 inches so that trees were not significantly grown, but merely subjected to beetle-induced mortality. After 5 years of simulated attack, we calculated the per-acre mean of live lodgepole pine in each stratum for each of the variables of interest. We compared the projected and the observed 1985 stratum estimates of live lodgepole pine in a variety of graphs and tables to see how well the model predictions matched the observed data. By limiting consideration to lodgepole pine only, we eliminated the confusing effects introduced into the analysis by species that are not addressed by the beetle model (but in reality may or may not be attacked by beetles).

Results

Figure 1 (page 16) is a graph of the observed 1985 basal area vs. the projected 1985 basal area of lodgepole pine within each stratum. The vertical bars represent the upper and lower 95% confidence about the estimated mean observed basal area, where the standard error was calculated using cluster sampling formulae (c.f. Cochran 1977). The bold line represents the condition where Y=X; if the observed and projected estimates agreed perfectly, all data points would fall on this line. One measure of the discord of the observed and projected estimates is based on the distance between the point and the Y=X line. Note that all 16 of the confidence intervals

intersect the Y=X line; this implies that in no individual case was there a statistically significant difference (at the 95% confidence level) between the observed and projected estimates of basal area. The points are approximately evenly distributed above and below the line, indicating no consistent trend towards overestimation or underestimation of stratum totals for this group of samples. The estimated correlation coefficient between observed and projected estimates of basal area, total cubic volume, total merchantable volume, and net board foot volume range from 1.00 to 0.77 for all trees, and from 1.00 to 0.84 for lodgepole pine only (Table 2, page 15).

We ran a regression analysis to test the simple linear model

$$\text{Observed basal area} = b_0 + b_1(\text{Projected basal area})$$

vs. the restricted model

$$\text{Observed basal area} = \text{Projected basal area}$$

using the standard F test. There was no statistically significant difference between the models ($P > 0.05$).

Discussion

The estimated correlation coefficients between observed and projected parameter estimates decrease in the order

$$\text{Number of trees} > \text{Basal area} > \text{volume},$$

which corresponds to the decreasing effect of small trees on the estimates of basal area and volume. Because (i) most of the stems fall in the smaller diameter classes and (ii) the beetle does not seriously attack small trees, no large change occurs in the total number of stems after a beetle

outbreak. The trees dying during the outbreak are the larger trees in the stratum, accounting for most of the basal area and volume. This emphasizes the importance of small differences in observed and projected numbers of trees in larger diameter classes; accuracy in basal area or volume estimates, or in estimating diameter distributions, is more relevant to model validation than accuracy in the total number of stems.

We plotted the percent difference in estimated basal area [(Observed - Projected)/Observed] vs. a variety of other variables to search for any patterns in the variation between observed and projected estimates. No relationship existed between the size of the difference and the site or productivity index. The absolute value of the difference tended to increase as the proportion of lodgepole pine in the stand increased (Figure 2, page 17). This trend leads both to underestimates and overestimates, and implies that projections for any specific stand may be suspect when lodgepole pine is a major stand component. This finding is not inconsistent; statistical models do not apply to individuals, they apply to populations. The Mountain Pine Beetle Model is used to predict average stand behavior. Based on the analysis presented in this paper, the model was reasonably successful. Underestimates and overestimates occurred with approximately equal frequency over the 16 strata.

There does seem to be a slight relationship between the difference and the proportion of live lodgepole remaining in the stratum in 1985 (Figure 3, page 18). The basal area proportion of live lodgepole ranged from approximately 75% to 95% over the 16 strata. Part of this is probably due to natural variations in beetle population density and success in attacking trees. However, another possible explanation for variation in live basal area is that the beetle epidemics

may not have been exactly 5 years old for all strata. Strata with a lower percentage of live trees may have had more than 5 years of epidemic, while stands with high percentages of live trees may actually have had less than 5 years. Projections based on strata with low percentages of live trees (say 75% to 83%) tended to underestimate the observed mortality. This would make intuitive sense if these strata actually tended to have more than 5 years of epidemic, while projections only considered the first 5 years. Conversely, projections based on strata at the upper end of the range (say 88% to 95% live trees) tended to overestimate mortality, as expected if these strata actually had less than 5 years of epidemic but model runs assumed 5 years. Projections based on strata in the middle of the range (83% to 88%) tended to have approximately equal numbers of overestimates and underestimates. We assume that some of the variation between observed and projected estimates is due to some uncertainty regarding exactly how long each stratum has been subjected to beetle epidemic. This illustrates the need for some kind of long-term permanent plot data to improve pest model validation.

We compared the 1985 observed and projected distributions of basal area by diameter class to check for possible diameter-specific bias in estimating mortality. Figure 4 (page 19) shows the difference between observed and projected estimates of basal area plotted vs. diameter class, with one observation for each diameter class in each of the 16 strata. After 5 years of outbreak, the model systematically underestimates mortality in the diameter classes less than 10 inches, and overestimates mortality in the larger diameter classes.

Some of the underestimation in the smaller diameter classes may be an artifact of our reconstruction of the 1980 population, where we changed all recently dead lodgepole pine into

"live" trees, regardless of diameter class. We had no way to distinguish between beetle-killed trees and trees that had died due to other causes. It might be possible to reduce the underestimation by adjusting the parameters in the growth and yield model that determine mortality rates of small trees. In a healthy stand, one expects that mortality of small trees might decrease if total stand basal area decreases, especially if mortality rates were density-dependent. However, in a stand undergoing a beetle epidemic, a reduction in basal area is indicative of a surge in the outbreak, so one might expect more smaller trees to die as well.

The overestimation of mortality in the larger diameter classes may be more serious. The model is designed to eliminate the largest trees from the stand first, with smaller trees eliminated in subsequent years (Cole and McGregor 1983). After 5 years of simulation, there were few trees greater than 20 inches in any projected stratum. In the field data, however, large trees did persist in almost all strata after 5 years of attack. The result is that after 5 years of simulated attack, the model tends to underestimate the live basal area in the largest diameter classes.

In reality, beetles probably do not attack the trees in a stand strictly in order of tree size; rather, they attack the larger trees in a limited area surrounding an infested tree. Because the largest trees in a stand may be rare and widely dispersed, large trees may persist in a stand until the beetle attack has covered the entire area. Even when attacked, large vigorous trees may survive for a finite period of time before dying; thus part of the difference may be due to observational errors in the field data caused by failure to detect infested but still healthy-looking trees. Technically, the model predicts infestation of trees by beetles and assumes that death is immediate. In actuality, there is a lag between infection and death; a tree takes a finite amount

of time to die. One might expect this to be especially true for those large trees that are still vigorous. These model assumptions are reasonable simplifications of the modeled system and are not expected to cause serious errors in the long run. Future modeling and inventory efforts might be justified in focusing on refining mortality predictions and measurements of the larger trees.

We hope to conduct a follow-up study to compare the observed and projected residual stands remaining after 10 years, when the beetle infestation has presumably run its course. Since a beetle epidemic of 10 years is a short length of time relative to the forest planning process, it is more important that pre- and post- epidemic strata estimates be accurate, and less important that the epidemic be modeled accurately over the 10-year cycle. The model has already been shown to be reliable in predicting residual stands following attacks in the intermountain region (Cole and McGregor 1983).

Conclusions

Although the Mountain Pine Beetle Model was calibrated using data from different ecosystems, the model worked reasonably well on average in the Deschutes National Forest; however, individual runs after 5 years of simulated attack (the approximate midpoint of the beetle outbreak cycle) can be positively or negatively biased by up to 15% in terms of basal area, and 25% in terms of volume. The model tends to underestimate the residual basal area in large diameter classes and to overestimate the residual basal area of small diameter trees after 5 years of attack. It is likely that the correlation between observed and projected values would be

increased (and the errors reduced) if one knew exactly how long the strata had actually experienced a beetle epidemic. Unfortunately, since beetles are endemic in many of these stands, it is difficult to identify the "start" of a major outbreak.

Until data from periodically measured permanent plots are available, the type of validation outlined in this paper may suffice for purposes of checking models. In any case, the growth and yield projections for lodgepole pine stands using the Mountain Pine Beetle Mortality Model should be much more realistic than models ignoring mountain pine beetle outbreaks entirely. While the mid-outbreak predictions might be sketchy, the decimation following the end of the epidemic should be easy to model.

Acknowledgements

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Table 1: Number of plots, and the projected and observed basal area for 16 strata from the Deschutes National Forest.

		Basal Area (ft²/acre)							
		All Species Together				Lodgepole Pine Only			
Stratum ID	No. of Plots	Projected 1980	Projected 1985	1985 Observed mean	1985 Observed se*	Projected 1980	Projected 1985	1985 Observed mean	1985 Observed se
Ponderosa Pine Forest Type									
1504	2	96.71	85.97	87.59	51.62	96.71	85.97	87.59	51.62
1508	6	111.3	99.03	105.3	15.82	69.65	57.00	63.63	12.12
1509	14	96.73	92.57	86.18	8.71	67.45	63.29	56.90	5.00
Lodgepole Pine Forest Type									
2206	8	107.9	105.1	101.6	13.67	47.18	43.99	40.83	6.51
2208	5	124.5	119.1	116.2	13.96	40.59	34.53	32.33	19.00
2209	6	104.6	104.1	100.5	9.90	58.33	57.42	54.16	10.93
2404	16	29.9	120.4	107.4	13.93	115.1	105.5	92.60	11.70
2406	15	103.1	74.78	89.91	8.96	92.21	63.70	78.99	9.34
2409	12	128.0	96.02	108.5	9.60	116.3	84.19	96.84	7.34
2504	36	99.99	90.44	83.27	6.48	92.62	82.99	75.91	6.30
2505	14	102.9	80.26	94.65	11.21	92.52	69.82	84.31	11.98
2506	37	113.2	92.84	97.93	7.52	99.87	79.43	85.16	7.11
2509	27	108.6	97.62	93.53	7.98	88.83	77.77	73.79	6.47
Mixed Conifer Forest Type									
3504	4	156.1	136.6	131.4	30.85	95.51	75.41	70.84	12.44
3505	4	130.3	120.0	118.7	17.54	83.03	72.10	71.42	12.23
3506	4	154.7	131.2	136.9	26.04	109.5	85.46	91.72	18.48

* = standard error

Table 2: Estimated correlation coefficients (Pearson's R) between observed and projected estimates of 5 parameters for all species and for lodgepole only.

Parameter	All species	Lodgepole only
Basal area (ft^2/acre)	0.89	0.90
Trees/acre	1.00	1.00
Total cubic foot volume	0.81	0.85
Merchantable cubic foot volume	0.77	0.84
Net board foot volume	0.83	0.84

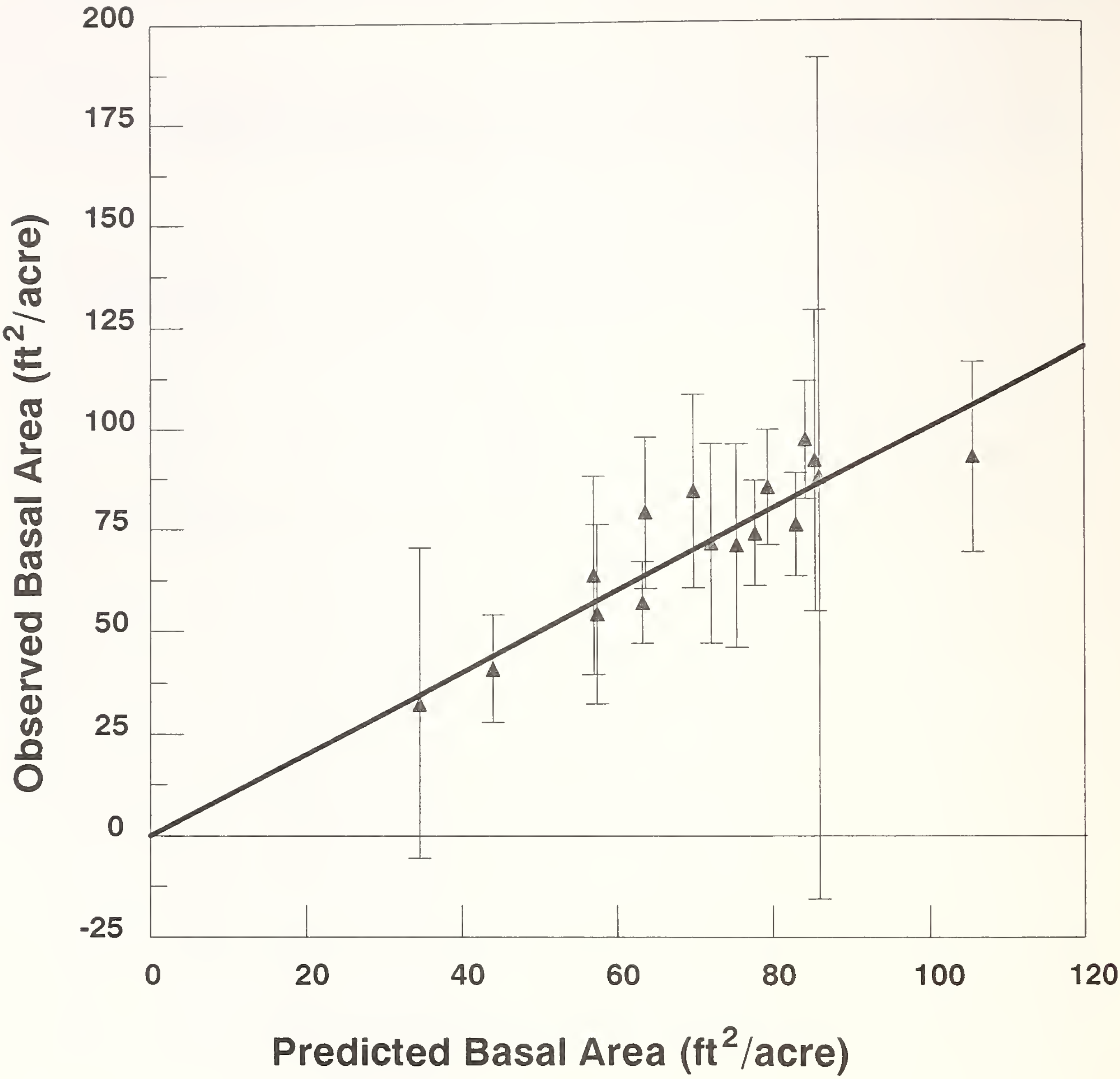

Figure 1: Lodgepole pine 1985 observed mean basal area (ft^2/acre) vs. 1985 predicted mean basal area (ft^2/acre). Vertical bars indicate the upper and lower 95% confidence interval estimates about the mean observed basal area. The dark line indicates the condition where Y=X.

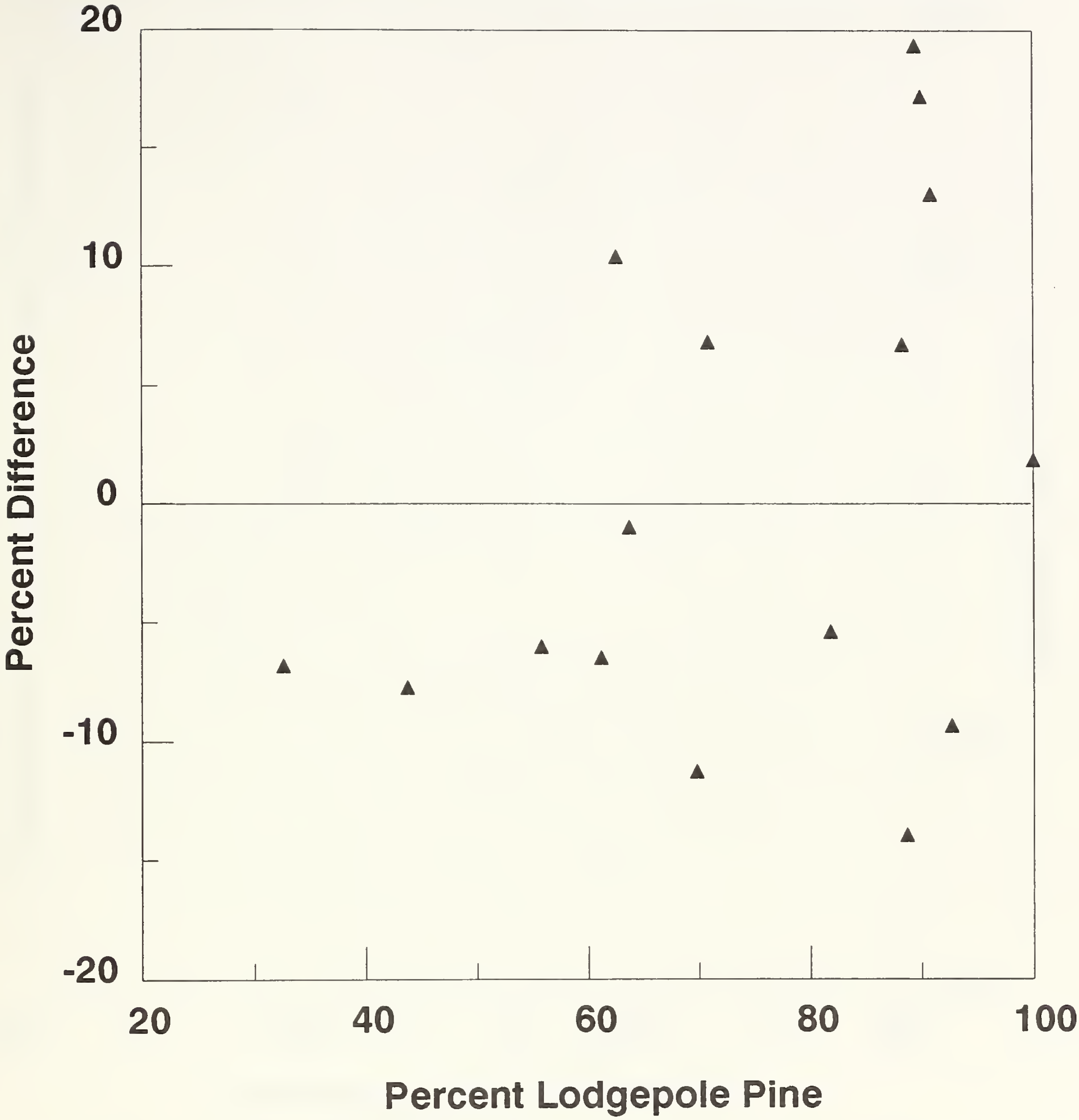

Figure 2: Percent difference in estimated basal area [(observed - projected) / observed] vs. the percentage of lodgepole pine in the observed stand in 1985.

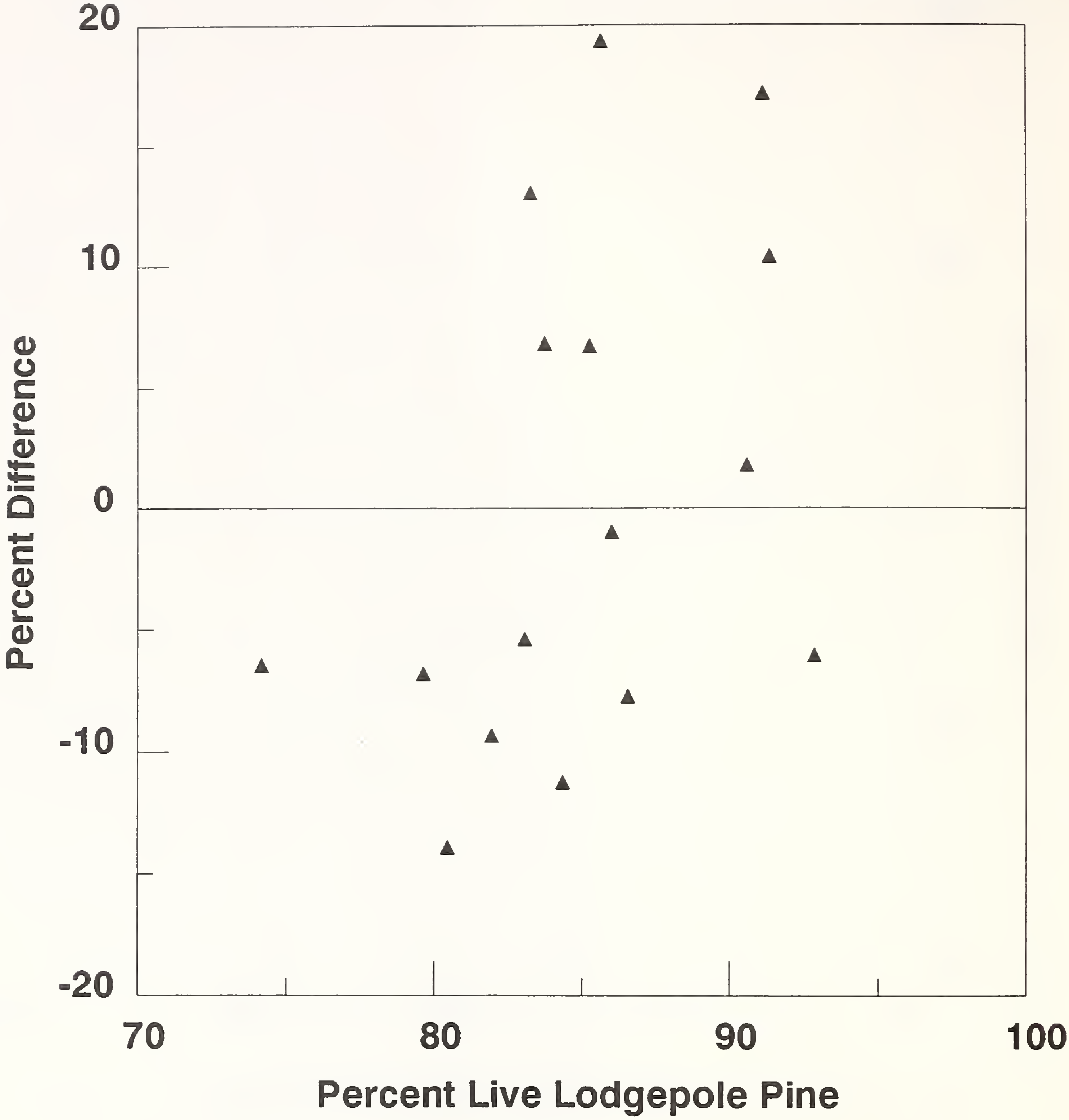

Figure 3: Percent difference in estimated basal area [(observed - projected) / observed] vs. the percentage of lodgepole pine observed to be alive in 1985.

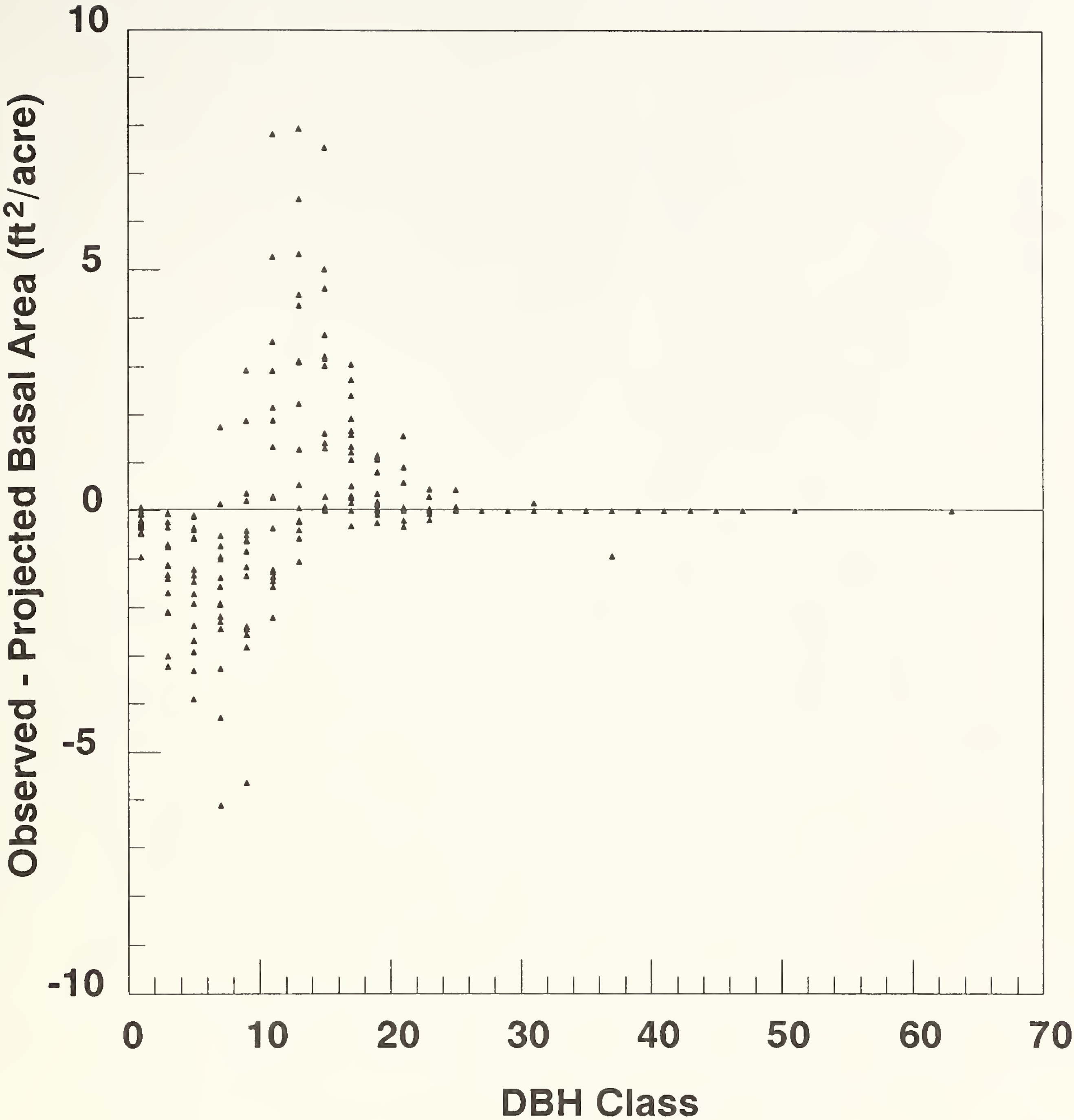

Figure 4: Difference in estimated basal area [observed - projected] vs. diameter class for all 16 strata.